

X-ray observations of 4 Draconis: symbiotic binary or cataclysmic triple?

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ABSTRACT

We present the first X-ray observations of the 4 Draconis system, consisting of an M3III giant with a hot ultraviolet companion. It has been claimed that the companion is itself an AM Her-type binary system, an identification that places strong constraints on the evolution of cataclysmic variables. We find that the X-ray properties of 4 Draconis are consistent with the presence of an accreting white dwarf, but not consistent with the presence of an AM Her system. We conclude that 4 Dra is therefore most-likely a symbiotic binary containing a white dwarf accreting material from the wind of the red giant.

The X-ray spectrum of 4 Dra is sometimes dominated by partially-ionised photoelectric absorption, presumably due to the wind of the red giant. We note that X-ray monitoring of such systems would provide a powerful probe of the wind and mass-loss rate of the giant, and would allow a detailed test of wind accretion models.

Key words: accretion, accretion discs – binaries: close – stars: individual: 4 Draconis – novae, cataclysmic variables – white dwarfs – X-rays: stars.

1 INTRODUCTION

Reimers (1985) reports the discovery of an ultraviolet companion to the M3III giant 4 Draconis. International Ultraviolet Explorer (IUE) observations show its spectrum is similar to that of high-accretion-rate cataclysmic variables, with a slowly decreasing continuum in the range 3000–1500 Å which then rises steeply to shorter wavelengths. There are strong and broad high-excitation emission lines (also typical of cataclysmic variables) and some narrow low-excitation emission lines which Reimers attributes to the ionised wind of the giant.

More detailed ultraviolet and optical-radial-velocity measurements are presented by Reimers, Griffin & Brown (1988). They determined the orbit of the giant and claimed that the ultraviolet flux is modulated at a period of 4 h. Based largely on this period, they conclude that the ultraviolet companion is most likely an AM Her-type cataclysmic variable.

Eggleton, Tout & Bailyn (1989) point out that the orbit of the wide pair in 4 Draconis ($P_{\text{orb}}=1703$ d) severely limits the size of the progenitor of a cataclysmic variable and places unique constraints on its evolution. Without constraints on even the inclinations of the two binary orbits they argue that any cataclysmic variable must have evolved from a progen-

itor with initial $P_{\text{orb}} \leq 100$ d. However Eggleton et al. also point out that the identification as an AM Her system is uncertain, and that an isolated white dwarf may explain the observations equally well. In this picture the white dwarf would be accreting from the wind of the giant and the four hour period would be its spin period. This requires a magnetic field on the white dwarf sufficient to funnel the accretion flow onto its poles.

In this paper we present the first X-ray observations of 4 Draconis, and discuss the nature of the system.

2 OBSERVATIONS

4 Draconis was observed four times with ROSAT (Trümper 1983): once during the ROSAT all-sky survey (RASS) with the position sensitive proportional counter (PSPC, Pfeffermann et al. 1987); twice during the pointed phase of the mission with the PSPC, once as the target and once serendipitously; and once with the high-resolution imager (HRI, Zombeck et al. 1995). A log of the pointed observations is presented in Table 1. 4 Draconis was detected in all four observations (see Sect. 3.1) and lightcurves and spectra were extracted from circular regions of radius 1.3, 6.0, and 0.6 arcmin for the 1991, 1993 and 1996 pointed observations

Table 1. Log of ROSAT pointed observations of 4 Draconis.

Obs. date	Instr.	Sequence no.	Off-axis ^a	Exp. ^b
4–5 Apr 1991	PSPC	300034	0	15.0
5–6 Jun 1993	PSPC	701225	51	5.7
8–20 Oct 1996	HRI	300492	0	41.8

^a Off-axis angle [arcmin].^b Exposure [ks].**Table 2.** Count rates and results of centroid fitting for the ROSAT observations of 4 Draconis. $\Delta\theta$ is the angular separation between the position of 4 Draconis and the fitted centroid of the spatial count distribution. HWHM is the half width at half maximum of the count distribution, also expressed as an angle.

Obs. date	Inst.	$\Delta\theta^a$	HWHM ^a	Count rate [s ⁻¹]	
				raw	corrected ^b
Nov 1990	RASS	-	-	0.033±0.008	0.048
Apr 1991	PSPC	0.26	0.35	0.011±0.001	0.011
Jun 1993	PSPC	0.6	3.1	0.371±0.008	0.707
Oct 1996	HRI	0.15	0.14	0.059±0.001	0.172

^a [arcmin].^b Corrected to PSPC on-axis response.

respectively. Background rates were estimated using large nearby regions free from obvious point sources. Raw count rates are presented in Table 2, as well as our best estimates of the equivalent on-axis PSPC count rate. The serendipitous off-axis observation has been corrected for vignetting and for source counts lost outside the selection radius (total factor 1.91). The RASS count rate (Huensch et al. 1998) has been corrected using an intermediate factor (1.45). The HRI count rate has been corrected using a factor 4.1 derived from PIMMS (Mukai 1993) and assuming our best fitting spectrum to the 1993 ROSAT spectrum of 4 Dra (see Sect. 3.2).

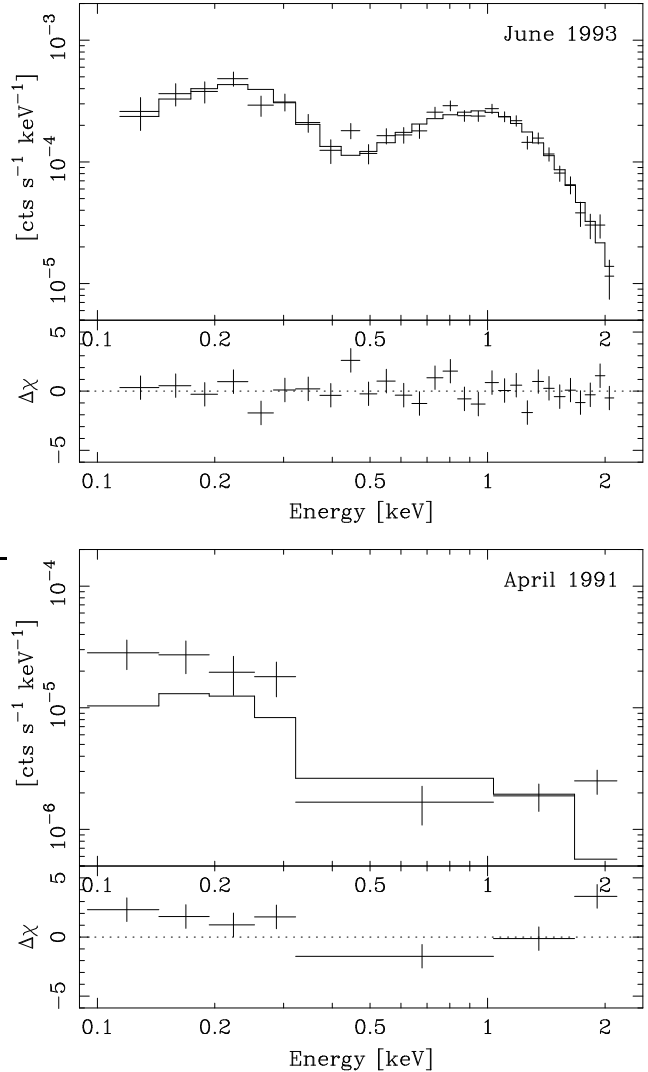
3 RESULTS

3.1 X-ray detection

An X-ray source is detected at the position of 4 Draconis in all three ROSAT observations. Table 2 shows the results of fitting for the centroid of the spatial count distribution. In each case the difference in position between the count centroid and 4 Draconis is less than or equal to the half width at half maximum (HWHM) of the distribution. The probability of chance alignment is small. For example, the probability of a single source lying so precisely at the centre of the HRI detector is $\sim 6 \times 10^{-5}$. There are only about ten sources detected in the image, so we are confident that the probability of chance alignment is $< 10^{-3}$ and that the detected source is 4 Draconis. The count rates presented in Table 2 show that it is highly variable.

3.2 X-ray spectroscopy

Figure 1 shows the spectra of 4 Draconis extracted from the two PSPC pointed observations. They have been fit with an

**Figure 1.** ROSAT PSPC spectra of 4 Draconis. Both spectra have been fit with a optically-thin thermal plasma model. The lower panel in each case shows the fit residuals scaled by the error on each data point.

optically-thin thermal plasma model (Mewe, Gronenschild & Van denOord 1985; Kaastra & Mewe 1993). The off-axis 1993 observation is well fit with this model, with a temperature of $4.4 \pm_{0.8}^{2.6}$ keV and absorbing column density of $(1.5 \pm 0.2) \times 10^{19} \text{ cm}^{-2}$ (reduced $\chi^2=1.05$ with 26 degrees of freedom). Figure 2 shows the constraints on these parameters. In contrast, the 1991 observation is very poorly fit with this model (reduced $\chi^2=6.7$ with 4 d.o.f.).

The unabsorbed 0.1–2 keV flux for the fit to the 1993 spectrum is $9 \times 10^{-12} \text{ erg s}^{-1} \text{ cm}^{-2}$. Including a bolometric correction factor of 2.4, this corresponds to a luminosity of $6 \times 10^{31} \text{ erg s}^{-1}$ at the HIPPARCOS distance of 4 Draconis (178 pc; Perryman et al. 1997).

The fit residuals for the 1991 spectrum show a minimum around 1 keV (Fig. 1) which corresponds to the maximum of the effective area of the PSPC and so must represent a true minimum in the X-ray flux. No physically-plausible pure-emission model can reproduce this minimum, but a partially-ionised absorber does so naturally. Photoelectric

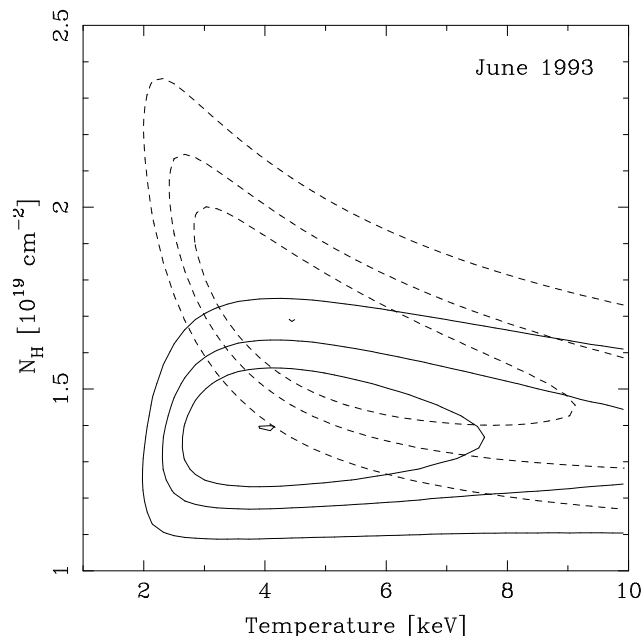


Figure 2. Contour plots of allowed parameter values for our fits to the 1993 PSPC spectrum of 4 Dra. Solid contours show the constraints on a bremsstrahlung model. Dotted contours show the constraints on the *mekal* plasma model. Contours represent 68, 90 and 99 per cent confidence for two interesting parameters ($\Delta\chi^2=2.3, 4.61, 9.21$ respectively).

absorption by cold cosmic-abundance material increases to low energies, but soft photons can leak through if low energy edges have been removed through ionisation. We find that such a model readily reproduces the observed 1991 spectrum, and we plot a typical fit in Fig. 3 (with hydrogen column density of $4 \times 10^{23} \text{ cm}^{-2}$ and ionisation parameter $\xi=5.8$). Unfortunately the combination of low spectral resolution and low signal-to-noise prevents a unique fit to an ionised absorption model and we cannot well constrain the properties of the absorbing medium. However, the wind of the red giant star is an obvious candidate absorber and the X-ray source itself may supply the photo-ionising flux. The difference between the 1991 and 1993 observations may be explained in part or entirely by a changing column density and/or ionisation fraction along our line of sight through the wind.

3.3 X-ray time-series analysis

The lightcurves from all three ROSAT observations reveal variability on short timescales. The lightcurve from the 42 ks HRI observation is presented in Figure 4. It shows strong variability on timescales between minutes and days, but there is no evidence for the four-hour periodic modulation claimed by Reimers, Griffin & Brown (1988) from IUE observations. Figure 5 shows the power spectrum of the HRI lightcurve, in which no obvious periodic signal is apparent. There is excess power close to the ROSAT orbital period (96 min), with the strongest peak at a slightly shorter period (86 min), and there is another suggestive peak at 37.5 min, but neither are sufficiently strong to represent a conclusive detection of periodic modulation.

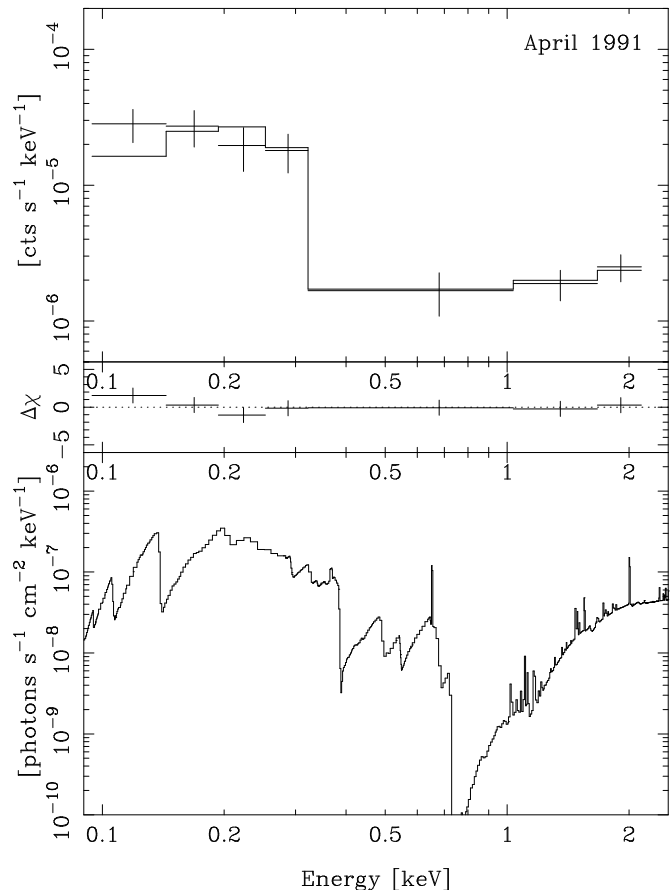


Figure 3. The 1991 ROSAT PSPC spectrum of 4 Draconis fitted with an ionised absorber model. The top panel shows the observed spectrum, the middle panel shows the fit residuals and the lower panel shows the model spectrum.

4 DISCUSSION

4.1 The nature of 4 Draconis

Previous ROSAT observations have shown that red giants are not substantial X-ray emitters. Only one late-type giant was detected in the ROSAT all-sky survey (Haisch, Schmitt & Rosso 1991; Haisch, Schmitt & Fabian 1992; Huensch et al. 1996), and pointed observations placed an extremely tight upper limit of $3 \times 10^{25} \text{ erg s}^{-1}$ on the X-ray flux of the K1 III red giant Arcturus (Ayers, Fleming & Schmitt 1991). Thus we can be confident that the X-ray emission from 4 Draconis reported in this paper originates on the ultraviolet companion, 4 Dra B.

Our ROSAT observations are consistent with this secondary containing an accreting white dwarf. The $\sim 5 \text{ keV}$ temperature of the optically-thin X-ray spectrum is characteristic of non-magnetic cataclysmic variables (e.g. Wheatley et al. 1996) and of the “bombardment solution” for radial accretion onto a white dwarf (e.g. Woelk & Beuermann 1995). The bombardment solution applies when the mass accretion rate per unit area is too low for a stand-off shock to form ($\dot{m} < 10^{-1} \text{ g s}^{-1} \text{ cm}^{-2}$). Our measured luminosity of $6 \times 10^{31} \text{ erg s}^{-1}$ implies an accretion rate of $0.24 - 1.8 \times 10^{15} \text{ g s}^{-1}$ for white dwarf masses in the range $0.3 - 1.0 M_{\odot}$. For the bombardment solution to apply this

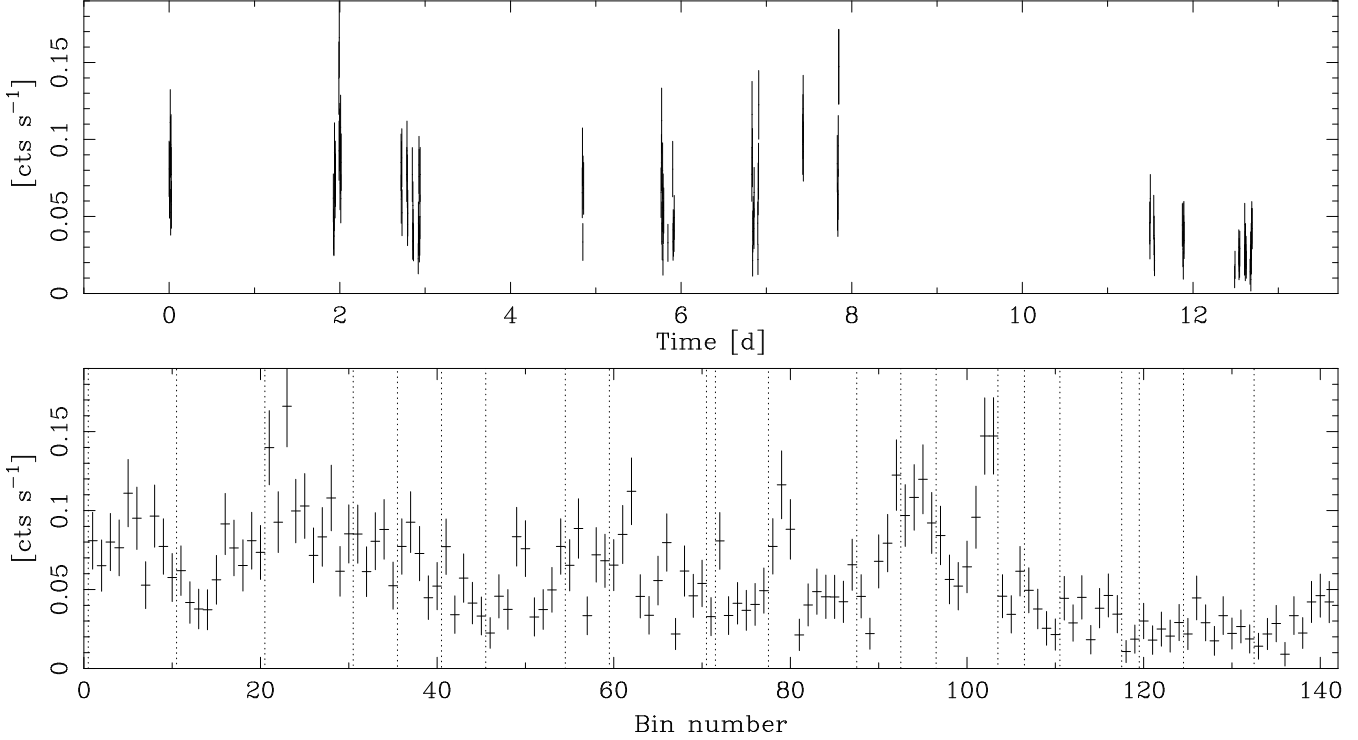


Figure 4. The 1996 ROSAT HRI lightcurve of 4 Draconis binned into 256 s bins. For clarity, data gaps have been omitted in the lower panel (dotted lines indicating breaks in the time axis). The top panel shows the full lightcurve.

accretion rate must be spread over an area of at least $0.24 - 1.8 \times 10^{16} \text{ cm}^2$, although this is a small fraction of the surface area of even a massive white dwarf.

Although our observations are consistent with the presence of an accreting white dwarf, they do not support the presence of an AM Her system. First, the ROSAT spectra of AM Hers are typically dominated by intense optically-thick soft emission, with characteristic temperatures of $\sim 20 \text{ eV}$. We can rule out the presence of such a component in the 1993 spectrum of 4 Dra B (Fig. 1). Second, it is clear from the HRI lightcurve (Fig. 4) that the X-ray emission is not strongly modulated at a period of 1–8 h, as it is for every known high-state AM Her system and most other magnetic cataclysmic variables.

AM Her systems have shown spectra much like that of 4 Draconis during low accretion rate states (e.g. Ramsay, Cropper & Mason 1995), but our measured luminosity is rather high for a low-state AM Her, and we believe the lack of an X-ray orbital periodicity alone is sufficient evidence to rule out the presence of an AM Her in the 4 Draconis system.

Non-magnetic cataclysmic variables (e.g. dwarf novae) usually have no optically-thick component in the ROSAT bandpass (e.g. Wheatley et al. 1996), have characteristic X-ray temperatures lower than AM Hers, and do not exhibit strong orbital X-ray modulation. Therefore we cannot rule out the presence of a non-magnetic cataclysmic variable. However, the original case for the presence of a cataclysmic variable was based upon the claimed detection of a 4 h ultraviolet period (Reimers, Griffin & Brown 1988). Reviewing the lightcurve in Fig. 3 of Reimers et al. we believe the case for a periodic modulation is not strong. Also, more

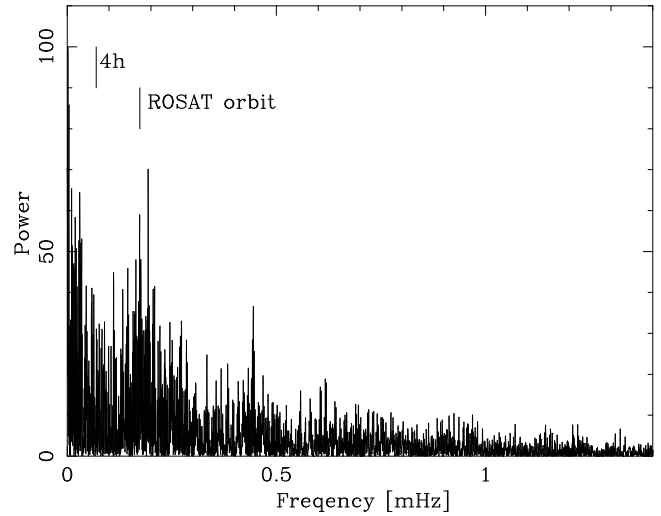


Figure 5. The power spectrum of the 1996 ROSAT HRI lightcurve of 4 Draconis.

recent HST observations do not support the presence of a 4 h period (B. Gaensicke, private communication). Thus, in the face of evidence clearly supporting the presence of an accreting white dwarf, but none requiring the presence of a third star, we conclude that the companion to 4 Draconis is most-likely a single white dwarf. The 4 Draconis system is then most-likely a symbiotic binary.

4.2 X-ray spectra of symbiotic stars

We note that the absorbed 1991 X-ray spectrum of 4 Dra is strikingly similar to that of the symbiotic star CH Cyg measured with ASCA (Ezuka, Ishida & Makino 1998). Muerset, Wolff & Jordan (1997) and Ezuka, Ishida & Makino (1998) interpret the X-ray spectrum of CH Cyg as a combination of accretion emission (hard X-rays) and the colliding winds of the two stars (soft X-rays). However, Wheatley (2001) and Wheatley (in preparation) reanalysed the ASCA spectrum and found that it could be interpreted instead as a single accretion-driven emission component viewed through a partially-ionised absorber. Our discovery of the same behaviour in 4 Dra shows that there is a distinct subclass of symbiotic stars in which the X-ray spectrum is dominated by complex absorption of a hard X-ray accretion-driven continuum. 4 Dra and CH Cyg seem to be distinct from the other symbiotic stars studied by Muerset, Wolff & Jordan (1997) which have much softer X-ray emission.

4.3 Absorption and orbital phase

Our results show a marked decrease in absorption between the 1991 and 1993 ROSAT observations of 4 Dra. If the absorption is due to the wind of the red giant, then the change in absorption may be related to our changing line of sight through the wind to the X-ray source.

Reimers, Griffin & Brown (1988) studied the radial velocity variations of the red giant and measured its orbital elements. They find a mildly eccentric orbit, $e = 0.3$, with a 5 yr period. The orbital phases of the two ROSAT PSPC observations, relative to periastron, are 0.22 ± 0.03 in 1991 and 0.68 ± 0.03 in 1993. It can be seen that the high absorption spectrum in 1991 was taken slightly closer to periastron, and the unabsorbed 1993 spectrum was taken slightly closer to apastron. Probably more importantly, the orbit is orientated such that the phase of the 1993 spectrum corresponds to a time when the X-ray source is in front of the red giant. This may explain the reduced absorption in this spectrum.

Figure 6 shows the long term X-ray lightcurve of 4 Dra using the estimated PSPC on-axis count rates for all four observations (see Table 2 and Sect. 2). It can be seen that the four ROSAT observations are consistent with a smooth variation in count rate with orbital phase.

Further observations are required in order to test whether the X-ray absorption in the spectrum of 4 Dra B really varies smoothly with orbital phase. We note, however, that a set of X-ray observations covering all orbital phases would provide a powerful probe of the wind and mass-loss rate of the red giant star, and would allow a detailed test of wind accretion models.

4.4 Wind accretion

In order to test our conclusion that 4 Dra B is most likely a single white dwarf accreting from the wind of the giant, we estimate the expected wind accretion rate in such a system. For the purpose of this order-of-magnitude estimate we assume the white dwarf is non-magnetic. A rotating magnetic field might act to reduce this accretion rate through the propeller effect.

The case of a white dwarf accreting from the wind of a

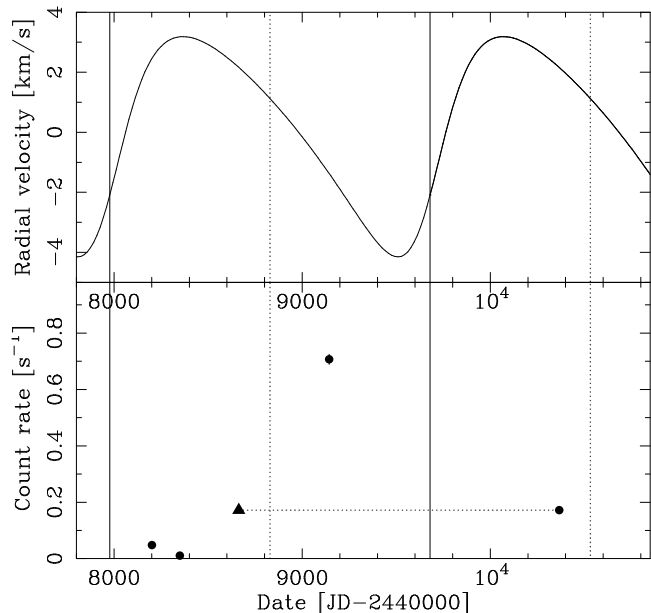


Figure 6. Long-term X-ray lightcurve of 4 Draconis (bottom panel) using estimated equivalent PSPC on-axis count rates for all four ROSAT observations (see Table 2 and Sect. 2). The 1996 HRI observation is plotted twice in order to show its relative orbital phase with respect to the other observations (triangle). The top panel shows the radial velocity of the giant star as determined by Reimers, Griffin & Brown (1988). The solid vertical lines represent periastron, and the dotted lines represent apastron. The orbital phase of the bright 1993 observation corresponds to a time when the X-ray source is in front of the giant.

red giant was treated by Livio & Warner (1984). Using their Equation 3 we find a wind accretion luminosity of $L_{acc} \sim 10^{34} \text{ erg s}^{-1}$ using the values: stellar separation $a \sim 4 \text{ AU} = 6 \times 10^{13} \text{ cm}$ (Reimers, Griffin & Brown 1988), wind velocity $v_w \sim 10 \text{ km s}^{-1}$ (Reimers & Schroeder 1989), orbital velocity of the white dwarf $v_0 \sim 30 \text{ km s}^{-1}$, and a wind mass loss rate $\dot{M}_w \sim 10^{-8} M_{\odot} \text{ yr}^{-1}$.

This luminosity is larger than both our measured X-ray luminosity, $6 \times 10^{31} \text{ erg s}^{-1}$, and the ultraviolet luminosity measured by Reimers (1985), $1 \times 10^{33} \text{ erg s}^{-1}$ (corrected to the HIPPARCOS distance, 178 pc). Many of the values used to estimate the wind accretion rate are uncertain, but it is clear that direct wind accretion is a viable energy source for the high-energy emission of 4 Dra B.

We note that the ratio of X-ray to ultraviolet luminosities is similar to that measured for the disc-accreting white dwarfs in dwarf novae (e.g. Wheatley et al. 1996).

The presence or otherwise of an accretion disc in a wind accretor depends sensitively on the relative velocity of the wind and accreting object (Livio & Warner 1984). Given the uncertainty in this quantity we cannot be sure whether or not an accretion disc is present around 4 Dra B. However, Reimers (1985) and Reimers, Griffin & Brown (1988) argue that the broad high-excitation emission lines of 4 Dra are more like those of AM Her systems than disc accreting dwarf dwarfs. This may point to the absence of an accretion disc in 4 Dra, with these broad high-excitation lines arising in the X-ray-illuminated, radial, accretion flow: a geometry much like that found in AM Her systems.

5 CONCLUSIONS

We present the discovery of X-ray emission from the symbiotic system 4 Draconis. The X-ray flux is highly variable on timescales from minutes to years. X-ray spectroscopy shows the spectrum is sometimes dominated by strong absorption by partially ionised material, probably the wind of the red giant. When free from absorption the spectrum is consistent with bremsstrahlung emission at a temperature around 5 keV. We conclude that these data are consistent with the presence of an accreting white dwarf, but that the lack of periodic X-ray modulation rules out the previously proposed identification of the hot companion as an AM Her system (Reimers, Griffin & Brown 1988). Instead we conclude that the companion is most likely a single white dwarf accreting from the wind of the giant. Consequently the evolutionary constraints derived by Eggleton, Tout & Bailyn (1989) need not apply. Finally, we show that wind accretion is a viable energy source in this system.

6 ACKNOWLEDGMENTS

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